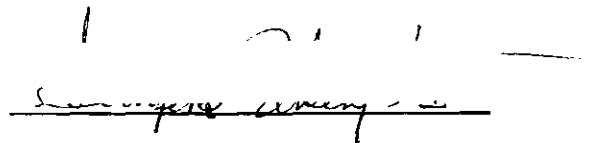


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A handwritten signature in dark ink, appearing to read "Samuel J. ...", is written over a horizontal line.

7/25/68

THE ALLOCATION OF TRIPS BETWEEN MASS TRANSPORTATION  
AND HIGHWAY FACILITIES IN METROPOLITAN AREAS

A THESIS

Presented by

The Faculty of the Division of Graduate  
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and

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THE ALLOCATION OF TRIPS BETWEEN MASS TRANSPORTATION  
AND HIGHWAY FACILITIES IN METROPOLITAN AREAS

Approved:

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Chairman  
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## INTRODUCTION

The recent trend of increasing trip volumes within metropolitan areas, due both to the rural-to-urban population migration and the increasing rate of tripmaking,<sup>1</sup> has increased the emphasis on total transportation system planning.<sup>2</sup> This planning emphasis rests primarily upon the two major modes of intraurban transportation, mass transportation and highway transportation; though the effects of other modes of transportation are analyzed as a part of the urban transportation planning process. The change in urban trip patterns is due primarily to an increasing number of highway trips and a declining number of mass transit trips; this is the cause for our increasing metropolitan transportation problem.<sup>3</sup> This overuse of intraurban highway facilities and the underuse of the mass transportation facilities translate into an inefficient and ineffective use of the urban transportation investment. In order to correct this imbalance in the urban transportation system, the transportation planner is increasing his efforts to determine the reasons why a tripmaker will choose his automobile over mass transit, a question which has been left unanswered since the late 1920's when the decline in mass transit use was first noticed.<sup>4</sup>

The immediate congestion problem may be solved by a new facility in an urban area; but without proper planning, it may not continue to be an effective solution to the problem of transportation congestion through the 20 or more years of its anticipated useful life. Therefore,

without a good estimate of the future trips by mass transit or highway, the new facility may not prove to be an efficient investment of the transportation dollar. The tool which the transportation planner uses to forecast the travel desires for mass transit versus the automobile is some form of transit estimating procedure, a procedure for allocating trips between mass transportation and highway facilities.

The purpose of this thesis is to aid persons, not technically familiar with the urban transportation planning process, in understanding the transit-use estimating procedures currently available to the transportation planner in order that he can make a decision as to which procedure is "best" for planning mass transportation facilities in his metropolitan area. Each of these procedures will be examined, by type and their advantages and limitations will be pointed out; also the technical terminology pertinent to an overview of the transit use estimating process will be explained. In order to accomplish this purpose, this thesis will be divided into three chapters:

1. Development of Mass Transportation Use Estimating Procedures--  
A summary of the types of data required and how these data are analyzed to develop a "calibrated" model or a model which will reproduce the "baseyear," or observed, transit use within an acceptable error of estimation. The process of forecasting these data for future year transit use estimation will also be explained.

2. Mass Transportation Use Estimating Procedures--The various modeling techniques which are used to develop one of the three currently

accepted estimating procedures: (1) direct generation, (2) trip-end modal split, and (3) trip-interchange modal split; will be examined.

3. A Balanced Transportation System--The transit use estimating procedure which appears to be the "best" planning tool currently available will be recommended.

The material contained in this thesis was obtained from a review of urban transportation studies and other pertinent literature on the subject of transportation planning, from interviews with transportation planners, and from the author's experience in dealing with the urban transportation planning process.

## CHAPTER I

### DEVELOPMENT OF MASS TRANSPORTATION

#### USE ESTIMATING PROCEDURES

The estimation of future mass transit use in a metropolitan area is generally done within the framework of a comprehensive, continuing, and cooperative transportation planning process. This process relates urban development to travel patterns and considers the advantages of both mass transportation and highway facilities for particular trips to insure that the facilities are comparable, not competitive; i.e.,:

1. A highway facility is not planned in the same corridor as a transit facility to serve a particular type of trip, such as a work trip to the CBD, which can better be served by mass transportation. However, the highway facility in the corridor might still be needed to serve other trip purposes, but because the work trip has been served by transit, a highway facility of less capacity would only be required.

2. In areas where a mass transit facility would be required, but a rail facility would supply more capacity than is necessary, a bus-way facility which could later be converted to rail as the travel demand increased might be justified.

3. Whenever a "fixed" mass transportation facility, rail or bus-way, is recommended, the highway facilities must be planned to insure adequate ground access to the stations.

This inclusive transportation planning process will minimize the cost of planning transportation facilities as the possibility of duplication of effort is reduced since planning for either type of urban transportation facility requires the collection and analysis of the same types of data relating to urban development and travel patterns. In several metropolitan areas, such as Atlanta, San Francisco, and Washington, D. C., where an administrative decision was made to plan a mass transit facility independent of highway facilities, the outcome of such studies has been expensive due to the cost of restudy to rectify the differences between mass transportation and highway facilities;<sup>5</sup> the decision to plan highway facilities independent of mass transportation, as in Los Angeles, has been equally as costly.<sup>6</sup> Therefore, the need for a transit use estimating procedure is valid whether the study area has only a handful of privately operated buses or a highly sophisticated and publicly subsidized rail and bus mass transportation network.<sup>7</sup>

The transit use estimating procedure is developing from an analysis of the data collected during the inventory phase of a transportation study. This procedure, or model, is then tested, or calibrated, in order that it will reproduce, or simulate, within an acceptable error of estimation, the existing, or base year, transit use. The model is then used to estimate future transit use using as inputs the future forecasts of urban activity. In making this estimation of future transit use, it is implicitly assumed that the same conditions which influenced transit use during the base year will

influence transit use in the future year.<sup>8</sup> Some planners argue that this process is invalid because such an assumption should not be made as a future mass transit facility will entirely change the existing transit use patterns.<sup>9</sup> However, the procedure is not static as future urban activity forecasts are inputs into the model for estimating future transit use; the transportation planner can also keep his model sensitive to changing transit use patterns by:

1. Monitoring the shift in transit use patterns and modifying his estimating model accordingly;<sup>10</sup> and/or
2. Augmenting his model by using transit use data obtained from other metropolitan areas which have experience in using the more advanced forms of mass transportation.<sup>11</sup>

A model is a representation of a "real life" event;<sup>12</sup> and may represent that event in any of several ways; the model types which have been used in transit-use estimating have been:

1. Mathematical. This is the method generally used in developing mass transit use estimating procedures for both base-year calibration and future-year transit use forecasting. These models have generally been expressed as an equation, curve, or surface relating transit use to the most significant factors influencing transit use.<sup>13</sup>

2. Physical. This method involves the use of a physical feature to represent the magnitude of an event, such as the use of a series of different height blocks to show the number of transit trip destinations by analysis zone; this model was used by the Chicago Area Transportation Study staff.<sup>14</sup>

3. Electronic. This method is the use of an electronic signal to make a trace across a cathode ray tube representing a transit trip; this model was also used by the CATS staff and similar traces were used as the cover design on their three published reports.<sup>15</sup>

The primary requirement on the relationships developed for use in the mathematical model, which is used in all transit use estimating procedures, is that the relationships developed be logical, stable, independent of other factors which influence transit use, easily forecast, and easily monitored and kept current.

The development and use of a mass transit use estimating procedure has three basic phases:

1. An inventory of existing transit use and the factors which are believed to be most significantly related to transit use.

2. An analysis of the inventory data to determine which relationships are most significantly and logically related to transit use; the significance of these relationships is generally determined by various statistical methods and their logical relationship is left to the judgment of the transportation planner. The result of this phase is the development of a "calibrated" mass transit use estimating procedure, or a procedure which most nearly reproduces the transit use observed by the inventory data.

3. Forecasting future transit use using the procedure developed during the analysis phase and the forecasted urban activity inputs.

The transportation planner then uses the forecasted transit use to determine the level, type, and configuration of the future mass

transportation facility he will recommend to the local policymakers which are responsible for the implementation of the future transportation system.

### Inventory Requirements

The urban activity in a metropolitan area is defined by the population, economy, and land use characteristics by type and location of the area; and this urban activity defines the travel patterns of that area. To determine the magnitude of the urban activity and the travel patterns, the transportation planner relies upon the skills of many professions, such as demographers, economists, city planners, and transportation engineers to inventory their areas of interest. Most of the inventory data can be obtained by technicians trained as to the type of data required; however, a specialist is needed to supervise the data collection in his area of interest and to make the necessary quality control checks to insure that the data being collected is logical.

The additional effort required to include the development of a transit use estimating procedure in a highway facilities planning study is minimal, and the rewards to the metropolitan area are far greater due to this broadened study which evaluates all phases of metropolitan transportation. When such a procedure is a part of an urban transportation study, there is little, if any, additional inventory data required for the model development as the same type of data is required for the development of the other travel models which would be part of a



highway facilities planning study: (1) trip generation, (2) trip distribution, and (3) trip assignment.

### Urban Activity

While the transportation planner requires only a small portion of the urban activity indicators, land use characteristics and selected population characteristics, to develop his transit use estimating procedure; an inventory of all the urban activity is required to insure that the future land use distribution and population characteristics will be compatible with the future urban activity in the metropolitan area. The inventory of these indicators are necessary to the city planner, the demographer, and the economist in helping them in their analysis of how the land in the metropolitan area is being used to support the people and their economic activities and to aid them in their forecasts of the future urban activity.

There are many sources from which the inventory of urban activity can be developed, and the size of the inventory will be limited only by the depth to which the planners consider necessary to develop the land use and population characteristics for the transportation planner and any use they have for urban activity data, such as the development of economic base studies and industrial site location studies. Some of the sources which would enable the development of the land use and population characteristics needed by the transportation planner are:

1. Population data from Census publications, locally maintained vital statistics records, Labor Statistics publications, State Employment

Security agencies, and/or home interviews.

2. Land use data from tax digests, building and occupancy permits, study of aerial photography, or land use surveys made in the field.

### Travel Patterns

The primary method by which travel patterns are inventoried is an origin-destination survey, which consists of finding out where a trip begins and where it ends. As a result of this survey, the transportation planner gets a "feeling for" the existing travel patterns, both as to magnitude and the types of trips which are required to serve the area's population. The five general types of questions asked by the interviewer during the O-D survey are:

1. How many trips did you make today?
2. What was the purpose of each trip?
3. How, or by what mode of transportation, did you make this trip?
4. Where did you go on each trip?
5. Where did each trip originate?<sup>16</sup>

Since the magnitude of the data that would be accumulated and the job that would be required in order to obtain these data on every trip made in the urban area, though desirable, would be impractical. The O-D survey required to collect this travel pattern data must be done using a representative sample: various manuals, such as *What is Scientific Sampling?*,<sup>17</sup> are available which explain how such a sample is selected.

There are two methods of use in obtaining O-D data: (1) the external cordon line and (2) the home interview. The external cordon line interview takes place at a station on a line delimiting the outer boundary of the transportation study;<sup>18</sup> however, this method is rarely used for obtaining transit use information as a transit system only serves the developed portions of an urban area which are generally within the external cordon. Therefore, the transit use information is primarily obtained by the home interview which collects information about the internal-internal trip. As transit use represents only a small portion of the total trips in a metropolitan area, the transit use data collected by the home interview should be supplemented by on-transit interviews and data from secondary sources.

Home Interview Study. The home interview study is a process in which the interviewer visits the selected dwelling unit and interviews each occupant as to his trips as well as other study data that might be required, such as family income and automobile availability. The data collected by the home interview can then be expanded to the whole traffic analysis zone in order to obtain the average travel habits within that zone.<sup>19</sup>

As the home interview is the most expensive method of collecting travel pattern data, other ways of collecting this data are being explored, such as telephone interviews and post card interviews, to reduce the cost of data collection. This author believes that a combination of the home interview and the telephone interview has greatest possibility of cost reduction and still obtaining unbiased data.

This method would be accomplished by first selecting the dwelling units to be sampled and then mailing out a post card requesting the telephone number as well as explaining the purpose of the interview which will be taken; then during the period selected for obtaining the O-D data, the persons having a telephone could be interviewed by telephone and data from no-phone and no-answer dwelling units would be obtained by a home interview. This method could make a larger sample available at less cost and remove the bias of missing no-phone dwelling units.

On-Transit Interview. The data collected by the on-transit interview is of little use in determining total travel activity, due to its mode bias, except in obtaining data on transit trips which began as auto trips outside of the study area, an external-internal bi-modal trip. However, the data are valuable in that the information obtained can be used in determining what factors caused a person to use mass transportation for a particular trip instead of his car, if he had one available to use. It also gives the transportation planner a better idea of what might happen if the same type of transit service were available in areas which have a low rate of transit use. In this survey, the same type of questions used in the home interview are used by the on-transit interviewer; except that he is not restricted to a set sample rate but rather by the time it takes him to complete an interview.

Secondary Data Sources. Because of the large expense and effort involved in doing interviews, more readily available data sources are being sought. One source of data is the decennial and special censuses conducted by the U. S. Bureau of the Census and another is the economic

statistics published by the U. S. Bureau of Labor Statistics; these two sources have been used in conjunction with each other to develop modal choice relationships. The "Journey to Work Survey" from the Census publications and "Special Labor Force Characteristics" from the Labor Statistics publications were used by transportation planners to develop a modal split relationship for work trips in the New York Standard Metropolitan Statistical Area.<sup>20</sup>

### Analysis of Data

During the analysis of data phase of a transportation study, the data collected from the various inventories is "taken apart" in order to develop the interrelationships which exist between the land use and population characteristics and the travel patterns. As these relationships are developed, it will be seen that some factors will indicate a strong relationship to automobile trips and others a strong relationship to transit; thus, the factor which the "average" tripmaker considers in making his choice between transit and the automobile will be developed. These relationships should be developed by specialists in interpreting the various data to insure that the relationships are logical and to determine if the data required for each relationship can be easily maintained and updated.

The factors which influence mass transit use can be placed into three general categories: (1) Tripmaker Characteristics, (2) Trip Characteristics, and (3) System Characteristics.<sup>21</sup> The transit use estimating procedure developed may include one or more of these characteristics and one or more of the factors within each category of these

characteristics; however, the number of factors used in an estimating procedure should be economic:

1. There should not be so many variables as to require the keeping of too many different items of data up to date.

2. There should be enough different variables to yield good statistical reliability, the maximum correlation with the minimum standard error.<sup>22</sup>

In developing the estimating procedure, continuations of the various relationships are used to reproduce the base-year transit use; the procedure which most nearly reproduces the base-year, with an acceptable error of estimation and is logical, is selected as the procedure to use in the forecasting phase.

#### Tripmaker Characteristics

The tripmaker characteristics include both social and economic factors which influence a tripmaker to choose between the available modes of transportation. Because of the qualitative nature of social characteristics, they are generally represented by a quantity describing the area in which the tripmaker lives. Similarly, the economic factors influencing transit use are described by selected population characteristics of the area in which they live.

Some tripmaker characteristics, such as family size (persons per family), land use intensity (single-, two-, and multi-family residential acres) at the origin of a trip, and population density (persons per acre), generally indicate an increase in transit use as they increase; while other characteristics, such as automobile availability (automobiles

per family or per dwelling unit) and income (average income per family or per family and unrelated individual), generally indicate a decrease in transit use as they increase. These tripmaker characteristics are those most commonly used in previous transportation studies.

### Trip Characteristics

The trip characteristics are those conditions which surround a particular trip and influence the mode of transportation to be used. The most commonly used trip characteristics are trip purpose and trip length.

In order to obtain trip purpose, it is necessary to know the type of land use at each end of the trip, and why a trip was made; i.e., a trip to a commercial land use may be for work or shopping.<sup>23</sup> There should always be at least three trip purposes used; (1) home-based work trips, (2) home-based non-work trips, and (3) non-home-based trips; however, the home-based non-work trips may be expanded depending upon the availability of data and the desirability of investigating the affects of other home-based trip purposes.

Trip length is generally considered to be the time it takes to make a given trip rather than the distance over which the trip is made; this being the commonly considered travel determinant in today's urban environment.<sup>24</sup> This measurement has been made in two ways, the air-line, or straight-line, distance between the origin and destination and the actual route distance, either of which is then converted to time.<sup>25</sup> Because automobile and transit travel times are generally compared by a ratio in transit use estimating procedure; some transportation planners

feel that such a ratio will tend to "mask" large absolute travel time differences; therefore, they desire to use distance measurement in their transit use estimating procedure.<sup>26</sup>

### System Characteristics

The vehicle, the traveled-way, and control devices are the major components of both mass transportation and highway facilities; but due to their physical differences, primarily in the vehicle and its traveled-way, they display different system characteristics. The basic difference is due to the flexibility of automobile route as compared to the government-controlled bus route and pick-up points or the fixed rail transit facility with its fixed terminals; however, the more fixed the facility, the higher the potential tripmaker capacity. Thus, the tripmaker has the opportunity to select the mode which most nearly fits his travel needs.

The most generally used system characteristics quantities to represent the quality of how well the existing or proposed type of transit facility will serve the future tripmaker are:

1. *Accessibility Ratio*-- A comparison of the relative ease by which an automobile trip and a transit trip can be made between the same origin and destination. This ratio is usually developed by using a gravity model, the theory and application of which can be found in most writings explaining transportation planning tools, such as *Calibrating and Testing a GRAVITY MODEL for Any Size Urban Area*.<sup>27</sup> When this ratio is developed comparing transit accessibility to highway accessibility, the higher the ratio the greater the transit use expected.



2. *Cost*--Generally, costs considered are expressed as a ratio of "out-of-pocket" costs of transit to automobile, such as the transit fare compared to the parking and gasoline and oil costs; the higher this ratio the greater transit use expected. However, as most people pay little attention to the costs of their automobile operation, it has little effect on their choice of travel modes.<sup>28</sup>

3. *Level, or Quality, of Service*--This is generally expressed as a ratio of "excess travel time" by transit to that by automobile, a comparison of the time required to make a trip which is spent outside of the vehicle.<sup>29</sup> The greater transit use is expected as this ratio decreases.

There are other qualitative system characteristics which have a relation to transit use, such as the availability of a seat, the reliability or adherence to a schedule, smoothness of the ride, and freedom from objectionable odors, which are not considered in developing a transit-use estimating procedure. Not considering these factors in developing the procedure is correct, as they are design considerations which can be "built into" the recommended mass transportation facility.

### Forecasting

Once there is a calibrated model, or a model which reproduces the base-year observations within acceptable error limits, they are then used to estimate future trips, using the land use and population characteristics which have been developed from the forecasts of urban activity. In order to carry out the travel forecasting process, two assumptions are made:

1. Urban activity will cause trips. This assumption should be made only as a basis of beginning the planning of a future transportation system, because urban activity and trips must be balanced to insure that sufficient trips can be made to support the forecasted urban activity.<sup>30</sup> In previous transportation studies, there was no way to balance urban activity to trips; but with the development of urban development models, such a balancing or iterative technique is available to transportation planning staffs.<sup>31</sup>

2. The same urban activity-travel pattern relationships which existed in the base year, the time period during which the initial data were gathered, will exist in the future-year, the time period which is the target of the forecasts.

As in the previous phases of transportation planning, the judgment of specialists in each area being forecasted should be used to insure that the forecasts obtained are logical. Also, as the area development forecasts are made by city planners, their judgment is necessary in deciding whether the forecast should be only a projection of the present development trends or a form of conceptualized development, such as satellite cities or new town clusters, depending on the overall development goals of the metropolitan area.<sup>32</sup>

### Urban Activity

The urban activity forecasts made in accord with the goals and objectives of the metropolitan area will estimate the number and distribution of people, how they will meet their economic needs, and how they will utilize the land in the future. The transportation planner

only uses the land use and selected population characteristics which are developed from the forecast of urban activity as the input into his models to forecast future travel patterns.

Because the requirement for input into the travel models is the same, regardless of the future development forecasted; the city planners can have several alternate development plans tested to determine the optimum, both as to urban activity and travel demands, as was done in several transportation studies, such as Southeastern Wisconsin and Twin Cities.<sup>33</sup>

#### Travel Patterns

Using the land use and population characteristics from the urban activity forecasts, the transportation planner will estimate travel patterns using the four basic travel models:

1. Trip generation models which determine the magnitude of future trips.

2. Trip distribution models which determine where the future trips will go.

3. Modal split models which determine how these trips will be made, by mass transportation or highway facilities.

4. Trip assignment models which determine which route these trips will use.<sup>34</sup> However, when direct generation of transit is used, a modal split model will not be used because in direct generation, transit trips are considered separate from automobile trips rather than a per cent of total trips within the study area.

## CHAPTER II

## MASS TRANSPORTATION USE ESTIMATING PROCEDURES

There are three methods of estimating currently being used in transportation studies, all of which are accepted by the Bureau of Public Roads,<sup>35</sup> the federal agency which is responsible for seeing that comprehensive transportation plans are formulated in each of the urban areas over 50,000 population;<sup>36</sup> these are, (1) the direct generation of transit trips, (2) the trip and modal split model, and (3) the trip-interchange modal split model. The modal split models are considered more representative of "real life" than direct generation because they relate both transit and automobile trips; thus simulating the preference of one mode over the other. However, to develop and use these more analytical models, both a transit and a highway option should be available to the tripmaker.<sup>37</sup>

Basically, each of the three estimating procedures differ only in when they are developed in the analysis phase and applied in the forecasting phase of the transportation planning process; Figure 1 illustrates the difference in the sequence of events;<sup>38</sup> for simplicity the feedback or balancing process is not shown. The direct generation process, a process which should only be used in small metropolitan areas with low transit use,<sup>39</sup> separates the base-year transit and automobile trips and the two trip types are not related until the future system forecasts are made, and then only to insure that the highway

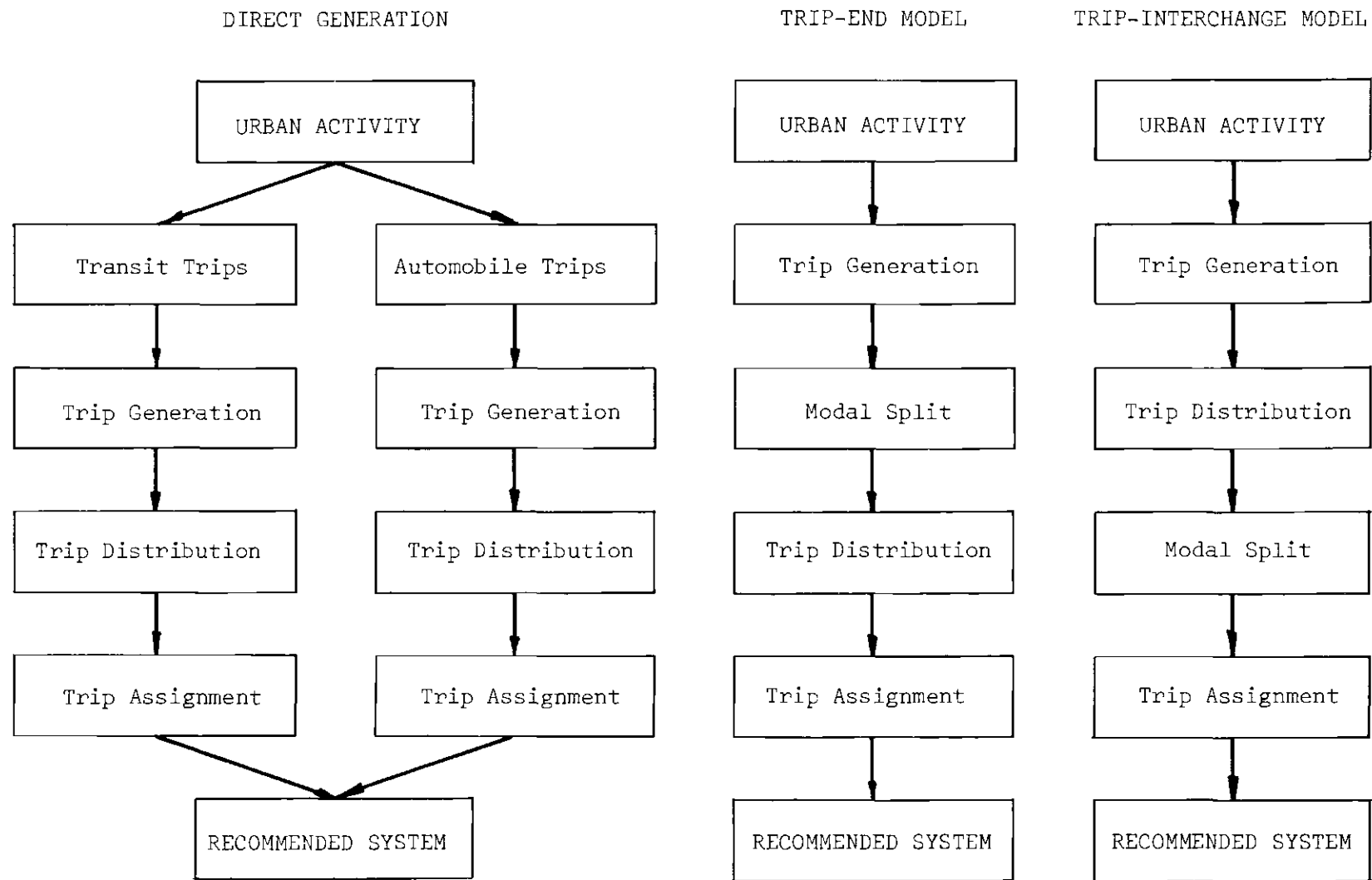


Figure 1. Typical Sequence of the Transportation Planning Process

facilities used jointly have sufficient capacity to handle both the forecasted bus trips and automobile trips. The trip-end model separates the person trip-ends into transit trips and automobile trips before trip distribution;<sup>40</sup> thus this model is sometimes called a "predistribution" model.<sup>41</sup> The trip-interchange model is developed to split person trips after trip distribution into transit and automobile trips;<sup>42</sup> therefore, it is sometimes referred to as a "post distribution" model.<sup>43</sup>

A transit use estimating procedure may be developed by any mathematical or statistical technique known, but because this process involves the simulation of human reactions, the metropolitan transportation studies reviewed used only the simpler modeling techniques which would yield acceptable simulations of observed modal choice. The modeling techniques commonly used are:

1. *Regression Analysis*--This method involves the reduction of related data to determine a straight line which "best" represents this data.<sup>44</sup>
2. *Cross-Classification*--This method involves the isolation or "pigeon-holing" of similar data, thus avoiding the assumption of linearity made when using regression analysis.<sup>45</sup>
3. *Data Fitting*--This method is similar to regression analysis in that related data are reduced to a linear form--in this case a curve--that "best" represents related data. This process may also result in a surface which is defined by the intersection of two curves plotted perpendicular to each other.

The use of these modeling techniques, which are *a posteriori*, or based upon observations, are subject to additional assumptions.

1. That the data observed will have a statistically normal distribution, or that individual data will not vary a large amount from an average of all data.<sup>46</sup>

2. That the data observed are not homoscedastic, or that they do not display identical characteristics with other observed data.<sup>47</sup>

These modeling techniques are not peculiar to any of the transit use estimating procedures; though usage has tended to limit the use of cross-classification to the development of a trip-end modal split model.<sup>48</sup> Similarly, regression analysis has been the only modeling technique used to develop a direct generation model, though cross-classification could also be used to develop this procedure. There are other mathematical or statistical modeling techniques which could be used by the transportation planner, such as multivariate analysis, and the use of Pearson's curves. However, in order to use those more sophisticated techniques, the services of a theoretical statistician would be required to insure that the techniques were being properly employed as their use to date has been restricted to research activities; the theory and possible application of these more advanced techniques can be found in texts such as *The Advanced Theory of Statistics*.<sup>49</sup> Also some of these techniques are relatively insensitive to slight changes in conditions, which limit their use in transportation planning.<sup>50</sup>

### Regression Analysis

The regression analysis technique was first used for developing a transit use estimating procedure by the Transportation Planning staff of the Chicago Area Transportation Study in the mid-50's as it was determined by the study staff that several factors, not time alone as had been used previously to estimate transit use, influenced transit use.<sup>54</sup> This technique allows the transportation planner to develop an estimating procedure that is "tailored" to the region under consideration by using only those factors which are most related, statistically, to transit use.

Regression analysis is a relatively simple statistical technique which can be used to measure the relationship of a wide variety of data, either linearly or nonlinearly. Because of its relative simplicity and flexibility, regression analysis is used in nearly all fields of empirical research;<sup>52</sup> as a consequence of its widespread use, many programs using this analysis technique have been written, or prepared, for computer use.<sup>53</sup> Similarly, this simplicity and flexibility have allowed regression analysis to be "tailored" for use in the development of each of the three forms of transit use estimating procedures.

Regression analysis as employed by transportation planners involves four major statistical operations, all of which are done in one computer "run." These are:

1. *Partial Correlation Analysis*--A method used to determine if collinearity exists between variables, or if the variables are strongly interrelated; variables should not be collinear in order to have a statistically sound estimating procedure.



2. *Computation of the Level of Significance*--In this method, the "F" number, a measure of statistical relation of independent variables to the dependent variable, is computed and only the variable with the highest "F" numbers are utilized in the regression equation.

3. *Regression Equation Development*--Generally, a simple linear regression is used in developing the equation; this method reduces scattered, related data points to a line which "best" represents this scatter in both slope and location. Figure 2 is a regression diagram illustrating scattered data points and the regression line which "best" fits.<sup>54</sup> The equation used in this technique is that of a straight line.

$$Y = a + bX,$$

where Y is the dependent variable or the unknown value being sought.

a is the intercept or regression constant.

b is the slope or regression coefficient.

X is the independent variable or the known value.

Because there is generally more than one variable affecting transit use, several regression computations will be made testing the effect of one variable at a time, or stepwise multiple regression; thus, the final regression equation will be the sum of one or more straight line equations.<sup>55</sup>

4. *Correlation*--This is a statistical measure of how well a regression equation "explains" all the data points; basically, there is a comparison of the computed dependent variable using the observed

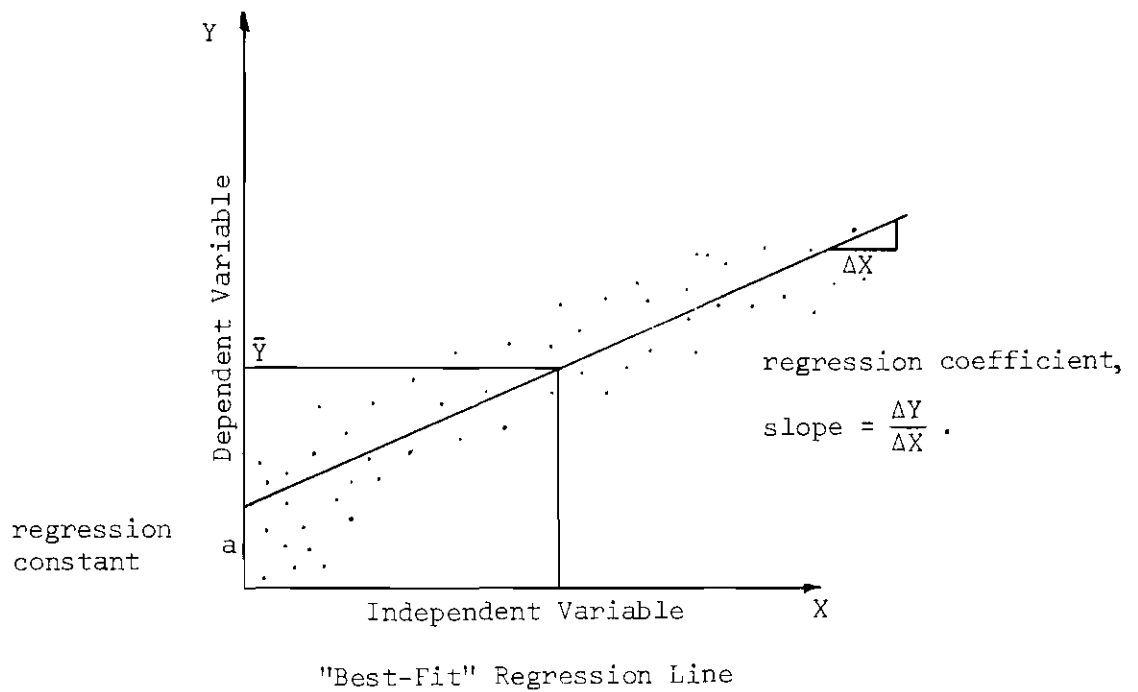
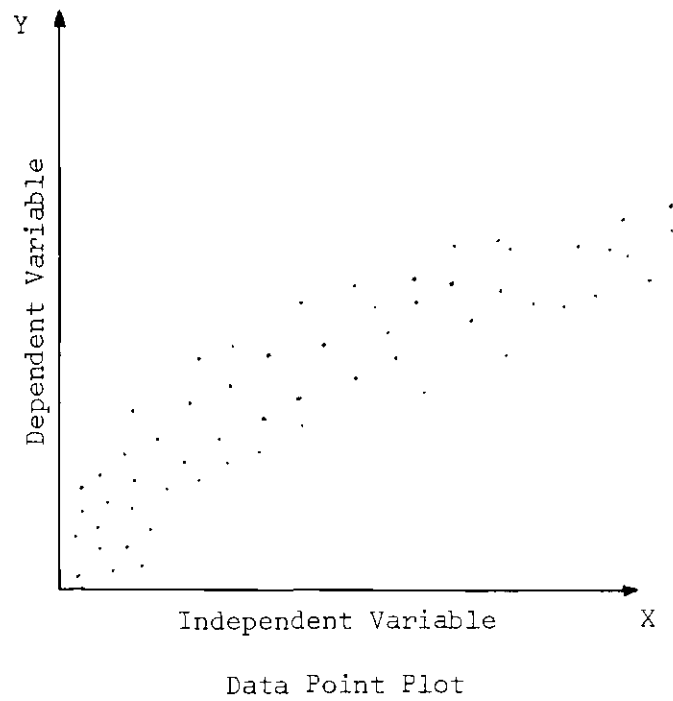


Figure 2. Typical Regression Diagram

values of the dependent variable to the observed data to determine how well the model simulates the observed condition. Ideally, the correlation coefficient would be 1.00, though this is rarely achieved; thus the correlation coefficient should be as close to 1.00 as possible.<sup>56</sup>

A more detailed discussion of the theory of each of the techniques may be found in most statistical texts, such as *Engineering Statistics*.<sup>57</sup>

Because of the apparent simplicity of the regression analysis technique and the speed in equation development using the computer, a statistically perfect but meaningless transit use estimating procedure may be developed. Thus, the need for the professional judgment of a transportation planner, most conversant with transit use, cannot be over-emphasized in the transportation planning process. For an estimating procedure to be "good," it must meet the statistical criteria established at the beginning of the transportation planning study and all independent variables must have a logical and consistent relation to the dependent variable;<sup>58</sup> i.e., the decrease in vacant land may relate well with transit use, but the development of this vacant land for single-family residences would have a decidedly different effect on transit use than the development of this land for an apartment complex.

Regression analysis has the advantage of speed of development of the final model because of the widespread availability of computer programs for its use. This method has a disadvantage as it "freezes," or holds constant, the rates of transit use regardless of the type of future transit facility to be used. This disadvantage can be reduced

by using similar transit use data from metropolitan areas already having the type of transit facility that is planned to modify the transit use models developed using the data from the planning area.

#### Direct Generation of Transit Trips

Direct generation of transit trips is an accepted tool for estimating transit in small metropolitan areas with a low rate of transit use,<sup>59</sup> but has not been widely used in transportation planning studies; thus, little is available which documents this method.

Direct generation is limited because it assumes that transit use and automobile use have no relationship to each other; and therefore have no effect on the use of the other. Such an assumption is not realistic and, therefore, should not be made unless mass transit is not presently available in the study area. This approach also helps to insure that the present auto-dominant systems will remain auto-dominant in the future. However, direct generation will aid in pointing out deficiencies in the present mass transportation facility which will be useful in formulating a short-range program of improvement for that facility, which is an important part of the transit plan in the small metropolitan areas.<sup>60</sup>

An example of the use of regression analysis direct generation is the home-based work production equation developed for Savannah, Georgia:

$$Y = -26.83 - 0.157X_1 + 0.77X_2,$$

where  $Y$  is the number of transit trips.

$X_1$  is the automobile registration.

$X_2$  is population.

The statistical measures used did not indicate that this was a "good" equation, but this indicates the problem of developing a model in areas of very low transit use. It is hard to obtain a "good" sample of transit use using sampling rates that would produce a "good" sample of automobile use data.<sup>61</sup>

A modified, but just as unrealistic, form of direct generation was used in the Detroit Metropolitan Area Traffic Study in that it was assumed that transit use would remain at the same ratio of total trips in the future as in the base year.<sup>62</sup>

#### Trip-End Modal Split Model

The modal split model developed in Chicago Area Transportation Study was the first such model developed using regression analysis. Though this particular model is not as desirable as some of the newer regression models because of its specialized units for land use input, the use of only tripmaker characteristics, and the use of automobile ownership instead of automobile availability, the methodology is still valid, and regression analysis is currently being used in transportation studies.

Partial correlation analysis was used on all the variables considered to affect transit use, the CATS transportation planning staff selected the two variables, net residential density and automobile ownership, for their modal split model; as these two variables were

most related to transit use and least interrelated. Both of these variables were characteristic of the origin end of the trip.<sup>63</sup> After regression, the final transit use estimating equation was:

$$Y = 19.7731 + 0.0610X_7 - 0.0365X_8,$$

where  $Y$  was the ratio in per cent of mass transit trips to total trips.

$X_7$  was the net residential density, persons per 100,000 square feet.

$X_8$  was car ownership, cars per 1,000 persons.

The correlation coefficient of this transit-use estimating procedure was 0.86.<sup>64</sup> This coefficient was calculated after the equation was developed by using the observed values of net residential density and automobile ownership to determine the per cent of transit use and comparing it to the observed per cent of transit use; here, the calculated and observed transit use values differed by 14 per cent. For example, in the base-year, Chicago area transit use amounted to 25 per cent of the total trips made;<sup>65</sup> therefore, the model may have estimated that either 21.5 per cent or 28.5 per cent of the total trips were made by transit.

#### Trip-Interchange Modal Split Model

The Twin Cities Joint Area Program used regression analysis to develop a trip-interchange modal split model; this model differs from the trip-end model in that the characteristics of both the origin and destination ends of a trip are used in the analysis process.<sup>66</sup> This type of model is more flexible than the trip-end model as it allows the calculated per cent of transit use to vary as conditions at either end

of the trip change; however, this model requires more base data to insure that a statistically significant amount of data is available about both trip ends.

The transportation planning staff of the TCAJP selected nine variables which they considered to be most significant in influencing a tripmaker to choose between transit or his automobile; these included one system characteristic and four characteristics of both the origin and destination zone of the trip.

- $X_1$  - A ratio of total travel time between the origin zone, "i," and the destination zone, "j," by transit (riding time "i-j," walk and wait time at "i," walk time at "j," and transfer time) divided by total automobile travel time (riding time "i-j," walk and unpark times at "i," and walk and park time at "j").
- $X_2$  - The median annual income of families and unrelated individuals in dollars.
- $X_3$  - The residential density in housing units per net residential acre.
- $X_4$  - Automobile availability in cars per housing unit.
- $X_5$  - Accessibility to employment, a ratio of the number of employment opportunities within 1/4 mile of a mass transit facility divided by the number of employment opportunities within 1/4 mile of a highway facility (the only facilities considered were shown on the traffic assignment network map).
- $X_6$  - Long-term parking cost, the average hourly rate for nine-hour parking in dollars.

$X_7$  - Short term parking, the average hourly rate for three-hour parking in dollars.

$X_8$  - Employment density in employment per gross acre.

$X_9$  - Accessibility to population, a ratio of the population within 1/4 mile of a transit facility divided by the population within 1/4 mile of a highway facility (the only facilities considered were shown on the assignment network map).

During the model development phase, the statistical tests employed in the regression analysis program indicated that automotive availability, accessibility to employment, and accessibility population did not have the significant effect on transit use that the staff had initially thought.<sup>67</sup>

The model development also pointed up one of the basic problems of using a trip-interchange, insufficient data to develop the models on an analysis zone basis to the desired level of statistical accuracy. The area-wide sampling rate of 5 per cent yielded less than 250 trip-interchanges, the level of observations determined to be necessary for a stable and unbiased sample, to some zones. Because of this problem the zones were aggregated up to districts; this procedure reduced the number of analysis areas by approximately one-third, from 450 to 153, while approximately doubling the correlation coefficients of the estimating equations, from 0.40 to 0.80 for the "work" trip equation and 0.79 for the "other" trips equation.<sup>68</sup> This modification, reducing the number of analysis areas, yielded the following transit use estimating equations:



$$Y_w = 41.4 - 12.1 \ln X_1 - 4.4 \ln X_2 + 8.0 \ln X_3 + 363.5 X_6 + 1.3 \ln X_8,$$

and

$$Y_o = 29.0 - 3.6 \ln X_1 - 3.2 \ln X_2 + 2.4 \ln X_3 + 285.2 X_7,$$

where  $Y_w$  was the per cent of total work trips by transit.

$Y_o$  was the per cent of total nonwork trips by transit.

$\ln$  is the natural logarithm of the variable following this symbol.

$X_1$ ,  $X_2$ ,  $X_3$ ,  $X_6$ ,  $X_7$ , and  $X_8$  are as explained above.<sup>69</sup>

### Cross-Classification

Cross-Classification which was first used by the Puget Sound Regional Transportation Study for the development of their trip generation model is a process of isolating bits of data within similar groups or ranges to determine the statistic which is most representative of the group. In the past, this method of analysis has been largely limited to research activities, but it is now being applied to transportation planning. This technique allows the transportation planner to develop a model using "representative" data rather than "average" data, because linearity is not assumed as it is in regression analysis. Table 1 shows a typical multi-dimensional matrix used in cross-classification, and Figure 3, the type of curves which are generated from this method.<sup>70</sup>

The advantages of cross-classification are freedom from the assumption of linearity, mentioned above; and freedom from being limited by the maximum observation because the largest group considered is "open

ended" (i.e., the maximum category considered would be "X or greater"), as shown by the matrix in Table 1.

Table 1. Typical Cross-Classification Matrix

Number of Persons Per Dwelling Unit	Average Total Person Trips Per Dwelling Unit				
	Number of Autos Owned Per Dwelling Unit				
	0	1	2	3 & Over	Weighted Average
1	1.03	2.68	4.37 <sup>a</sup>	-	1.72
2	1.52	5.13	7.04	2.00 <sup>a</sup>	4.38
3	3.08	7.16	9.26	10.47	7.46
4	3.16	7.98	11.56	12.75	9.10
5	3.46 <sup>a</sup>	8.54	12.36	17.73 <sup>a</sup>	10.16
6-7	7.11 <sup>a</sup>	9.82	9.61	16.77 <sup>a</sup>	11.00
8 & Over	7.00 <sup>a</sup>	9.65	6.18	11.00 <sup>a</sup>	12.24
Weighted Average	1.60	6.62	10.53	13.68	6.58

<sup>a</sup>Average based on fewer than 25 samples.

While the mechanics of this method are relatively simple, isolating data into predetermined categories or strata can result in unwanted bias; therefore, the transportation planner must select each strata carefully in order that each will be meaningful, representative of observed conditions, and the data easily forecast so that it will have the same meaning in the forecast year as it does in the base year. The major disadvantage of this method is that it has not been widely used in

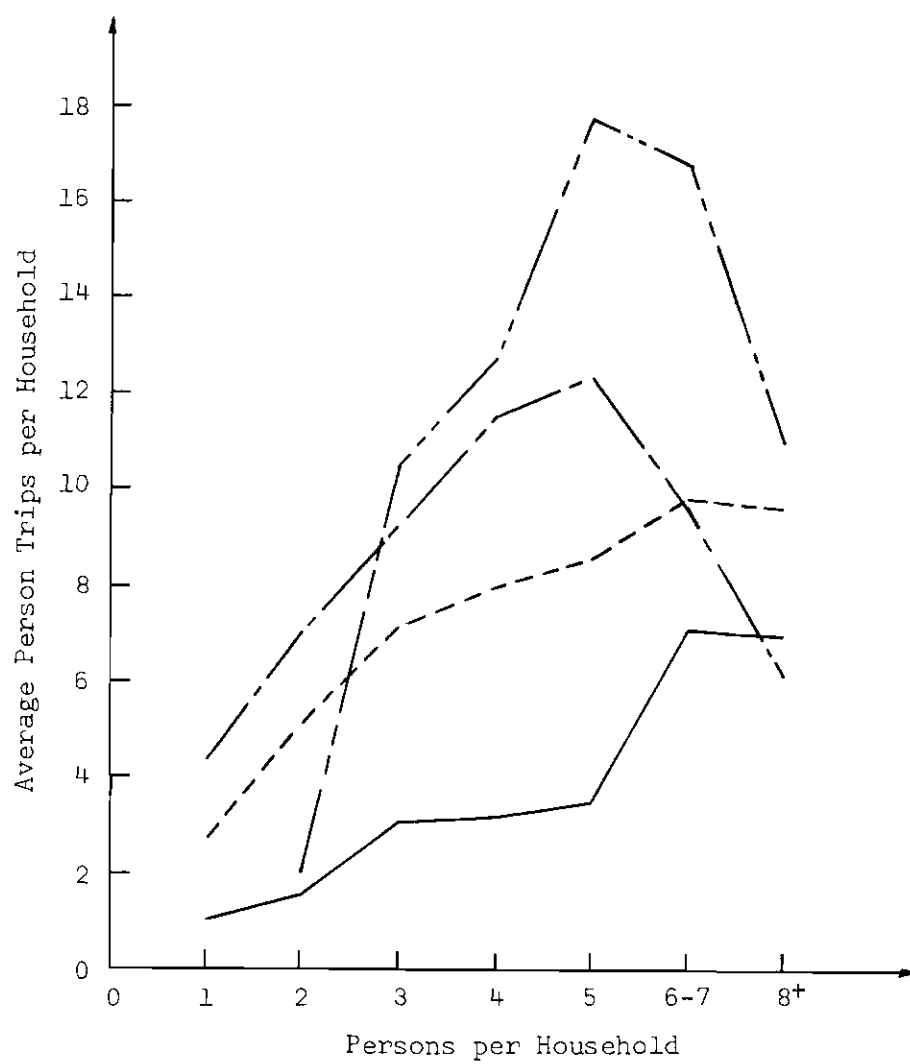


Figure 3. Typical Cross-Classification Curve

transportation planning; thus, the program batteries needed for computer application of this technique are not as readily available as are programs for regression analysis. Another disadvantage of this method is that as the number of stratifications increases, the sample must increase; and even then, some of the data cells in the matrix will contain an insufficient number of observations to be a statistically valid input into transit estimating procedure.<sup>71</sup> A third disadvantage of cross-classification is that it "freezes" or holds the analysis area transit use constant regardless of the type of transit system used; however, this limitation is negated by the assumption made at the beginning of transportation planning studies, that future trips will be influenced by the same factors that influence trips in the base-year.

#### Direct-Generation of Transit Trips

Although cross-classification is not presently used for direct generation of transit trips, it could be used for this method of transit-use estimation in small urban areas having a low rate of transit use. This is due to the simplicity that of this method which allows it to be done "by hand," the transit facility in the smaller urban areas will be primarily bus operating in "mixed" traffic, or using highway facilities jointly with automobile, which generally will not change during the forecast period, and in areas where no bus facility presently exists, the transit use data from a city of similar size and characteristics can be used for the forecast of future transit use.

### Trip-End Modal Split Model

The trip-end modal split model developed in the Puget Sound Regional Transportation Study, although a modified form of cross-classification indicates quite well how this method is used for estimating transit use.<sup>72</sup> Cross-classification was used in the beginning stages of the estimating procedure development summarizing the observed transit use data by purpose and income to prepare four smooth-curve transit-use graphs having three curves each indicating income level plotted against an accessibility ratio. When the curves were tested to determine if they substantially reproduced the base-year transit use observations, it was found that they underestimated transit use in the dense CBD area and greatly overestimated transit use in less dense suburban areas. In order to remedy this geographic bias, the PSRTS staff elected to develop a second cross-classification matrix correlating the over and under estimation of transit use to the same three income classes and four trip purposes used to prepare the curves plus three levels of automobile ownership and ten levels of population density. From this second matrix, 360 correction factors were developed for the 624 analysis areas in the region.<sup>73</sup> The adjusted transit use rate was then developed by multiplying the per cent of transit use obtained from the transit use estimating curves by a correction factor from the second cross-classification matrix.

In the PSRTS modal split development, as in all applications of cross-classification, the mathematical operations of analysis and forecasting are secondary to the judgment the transportation planner uses to

determine the ranges of each "data cell," this being the key to the effective use of this modeling technique. The four trip purposes, (1) home-based work, (2) home-based shopping, (3) home-based social-recreation, and (4) home-based miscellaneous, were selected because the staff considered them the most significant components of the travel in Puget Sound. The three income ranges (1) low--under \$4,500 per year, (2) Medium--\$4,500 to \$6,000 per year, and (3) high--\$6,000 per year and over, were used because a transition from no-car to one-car to multi-car households were noted at these income levels. Three automobile ownership levels, (1) low--under 0.80 autos per household, (2) medium--0.80 to 1.20 autos per household, and (3) high--1.20 autos per household and over, were selected because at these levels there were significant changes in transit use patterns, decreasing as automobile ownership increased.<sup>73</sup> The same reasoning based upon significant changes in transit use patterns was the basis for selecting the ten levels of net residential density expressed in persons per residential acre, (1) 0-15, (2) 16-19, (3) 20-22, (4) 23-26, (5) 27-30, (6) 31-37, (7) 38-45, (8) 46-59, (9) 60-80, and (10) 81-99.<sup>74</sup>

Because the selection of ranges is subjective and transportation planners may not agree in this selection, it is more important to document how the ranges were selected than to give the limiting values of each range.

#### Data-Fitting

The technique of data-fitting is relatively easy as it only requires the user to relate a dependent variable to one or two

independent variables depending upon whether he desires to develop a curve or a surface for transit use estimation. For simplicity, a curve will be used for illustrative purposes. Figure 4 shows a curve which relates a dependent variable, transit use as a per cent of total trips, is plotted against an independent variable, the travel time ratio by transit to automobile travel time.<sup>75</sup>

The advantages of using a data-fitting technique are:

1. It is relatively easy to understand and use.
2. It has been used in several transportation planning studies, so the documentation of the mechanics of this technique are available.<sup>76</sup>
3. No forecasted data can exceed the validity of the predictive element, a curve or a surface.

Data-fitting has many of the disadvantages of both regression analysis and cross-classification, these are:

1. As the user will generally take a "best fit" approach to preparing the predictive element, he will tend to "mask" any unusual conditions which may be peculiar to the area.
2. Care must be exercised in the selection of the independent variables, such that they are logical, stable, and easily forecast.

To overcome some of the disadvantages of this method, the transportation planners using it have modified it as discussed in the following paragraphs.

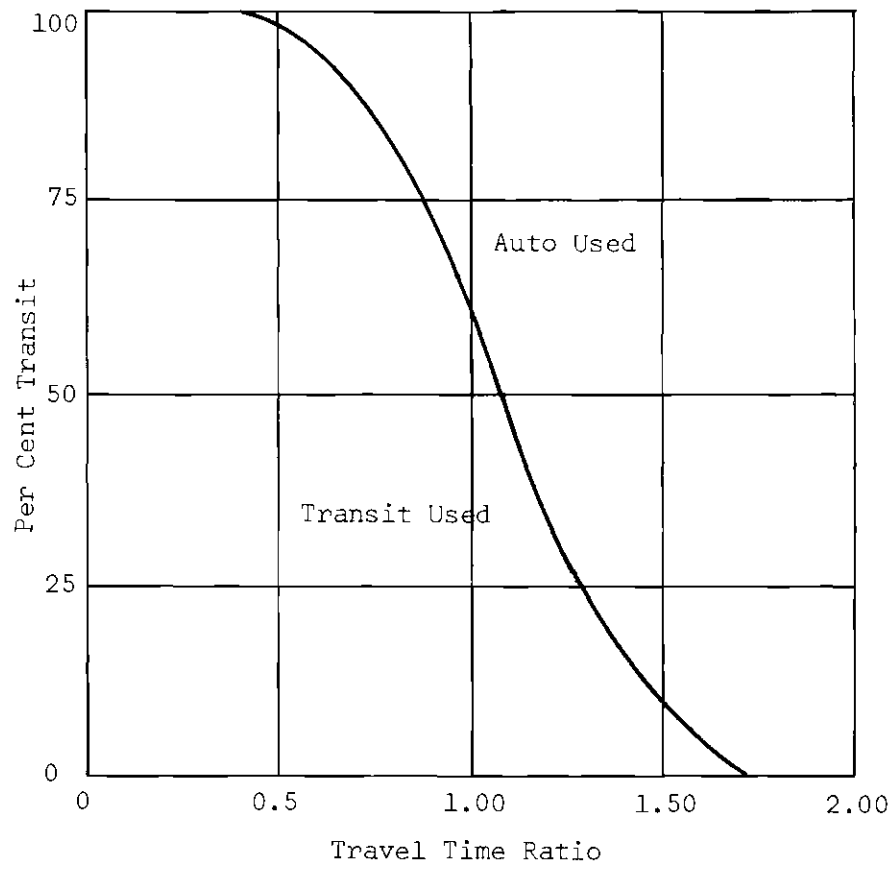


Figure 4. Typical Transit Use Curve



### Transit Use Curves

Transit use curves developed during the development of a transit use estimating procedure have generally been used in trip-interchange modal split models. The curves developed, to date, have been based on both an areal aggregate approach, where a curve or family of curves is developed to represent the modal split throughout the area, or a zonal aggregate approach, where many curves are developed on an area-wide basis but only the curve which "best" represents the modal split within an analysis zone is used in the forecasting phase to estimate future transit use.

Areal Aggregate Curves. The use of an areal aggregate curve grew from the classic transportation planning tool, the "diversion curve." The transportation planners adopted the "diversion curve" approach because the theory appeared sound as:

1. It recognized travel time as a determinant in the use of one transportation facility over another.
2. It gave the person planning a facility a good estimate of the volume of traffic which would be diverted to the new facility which would operate at a higher speed requiring less travel time than the older, slower facility when both serve the same destinations.<sup>77</sup>

However, a major limiting factor of the diversion curve was overlooked as it was developed for highway--major thoroughfare planning where the mode of travel was the same, by automobile, not the bi-modal transportation planning for which it was to be used. Because of this limitation, the areal aggregate curve was abandoned for modal split work in the

Chicago Area Transportation Study. The example of an areal aggregate curve shown in Figure 4 was the curve developed prior to CATS by the Cook County Highway Department to estimate transit use.<sup>78</sup>

When the San Francisco Bay Area Rapid Transit Study was begun, the transportation planning staff decided to take another look at the diversion curve theory. After studying earlier work in this area, it was decided that the approach was sound and only required additional field samples to be proven valid. It was then determined to take about 15,000 automobile and transit interviews to determine what influenced a person to decide between mass transportation and an automobile as a way of making his trip. This sample represented about 7.5 per cent of the average daily volume of trips through the Peninsular corridor. From the interview data, ten major categories, some having several subcategories, of trips were tested against seven measures of highway-transit trip comparisons and 113 preliminary transit use curves were developed having statistically valid trip volumes. Several statistical checks were employed to reduce this number of curves to 17 which were further refined by comparison to "known" curve equations in order to smooth them out. After further curve consolidation and comparisons with curves developed with data from other study areas, six curves were selected for use in estimating future transit use in the Bay Area; these curves estimated the per cent of total trips by transit knowing the travel time ratio, transit to highway, between any two zones. Two of the curves were for application in the internal area, San Francisco and East Bay, for CBD and non-CBD trips; and the remaining four curves were

applicable to the region outside of the internal area for CBD and non-CBD, peak period, peak direction work trips and CBD and non-CBD, all other trips.<sup>79</sup>

Zonal Aggregate Curves. The zonal aggregate curves used in the early transportation study for the Washington, D.C., area by the National Capital Transportation Agency were similar to the curves developed during the modal split analysis of the Metropolitan Toronto Transportation Study six years earlier.<sup>82</sup> These zonal aggregate curves were hybrids of the areal aggregate curve approach since they were developed using area-wide data, but only the curve which "best" reproduced the base-year modal split in a zone was used in estimating the future transit use.<sup>81</sup>

Based on their analysis of the O-D data, the NCTA staff determined that the greatest transit use was during the morning "peak hour"; thus, the major trip purposes were work and non-work.<sup>82</sup> This decision to develop an "AM" peak model was not totally independent as the National Capital Transportation Agency had been established to determine the feasibility and the type of mass transportation system to recommend for the Washington area<sup>83</sup> and justification for a mass transit system can best be determined during a "peak" period of trips to the same general locations, such as work trips to the many office complexes in downtown Washington; however, this bias does not detract from the validity of this modal split approach. Next, the staff considered several factors which influenced the use of transit; but as several of these factors were found to be linearly dependent with one or more other variables under consideration, they were no longer considered. The final list of

factors considered, in addition to trip purpose, included:

1. The relative travel time ratio of transit to highway travel time.

2. A ratio of relative travel cost which was a comparison of "out-of-pocket costs," by transit to those by automobile.

3. A level of service ratio which was a comparison of excess travel time by transit to that by automobile, excess travel time being defined as that time necessary to a trip but spent outside of the vehicle while enroute.

4. The economic status of the tripmaker as established by the average income of families and unrelated individuals.

In addition to the two trip purposes, the other factors were further stratified as it had been determined in the Toronto study that such stratifications were necessary for forecasting; these stratifications were:

- |                            |                              |
|----------------------------|------------------------------|
| 1. <i>Cost Ratio</i>       | 0 to 1.0                     |
|                            | 1.0 to 1.5                   |
|                            | 1.5 to 2.5                   |
|                            | 2.5 and over.                |
| 2. <i>Level of Service</i> | 0 to 1.5                     |
|                            | 1.5 to 3.5                   |
|                            | 3.5 to 5.5                   |
|                            | 5.5 and over.                |
| 3. <i>Income Level</i>     | \$ 0 to \$3,100 per Annum    |
|                            | \$3,100 to \$4,700 per Annum |
|                            | \$4,700 to \$6,200 per Annum |
|                            | \$6,200 to \$7,500 per Annum |
|                            | \$7,500 per Annum and Over.  |

Each of these stratifications were used as the predictive element on a graph of transit use as a per cent of total trips vs. travel time ratio;

this process resulted in a family of 160 transit use graphs (2 purposes  $\times$  4 cost ratios  $\times$  4 service levels  $\times$  5 income levels). In order to handle this large number of modal split relationships, the staff prepared, or wrote, a computer program to handle this modal split model.<sup>84</sup>

#### Transit Use Surfaces

The development of transit use estimating surfaces, used to date, is similar to the approach used in developing transit use curves, except that two curves are developed for each surface and the surface is formed by the intersection of these two curves; see Figure 5 for an example of a transit use estimating surface.<sup>85</sup> A transit use surface has been used in the development of both trip-end and trip-interchange modal split models.

Trip-End Modal Split Model. The staff of the Southeastern Wisconsin Regional Land Use-Transportation Study elected to use a surface for estimating the modal split in the region. They believed that this approach would give them a modal split model which would contain the three major factors which influence transit use: (1) Tripmaker Characteristics, (2) Trip Characteristics, and (3) System Characteristics. First, the trip characteristics were isolated by preparing surfaces for the work, other, and non-home based trip purposes; in addition, in Milwaukee a fourth trip purpose was used, the shopping trip, this purpose was included in the "other" trips in the remainder of the region. After several tests of the variables, selected by the study staff, for stability, reliability, sensitivity, and ease of forecasting, automobile availability (the average number of automobiles available per

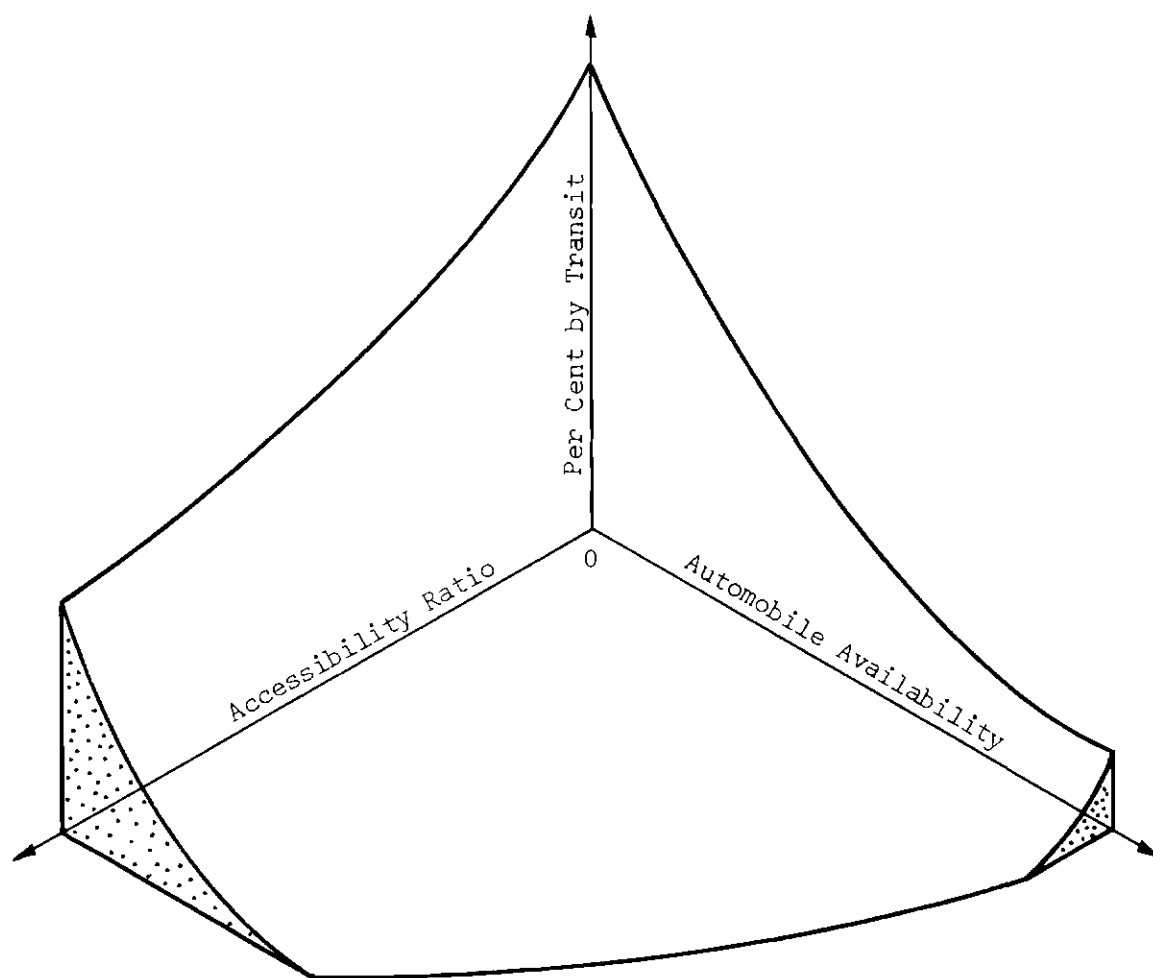


Figure 5. Typical Transit Use Estimating Surface

household) was selected as the tripmaker characteristics; the system characteristic selected for use in the transit use estimating surface was the accessibility index (a ratio of travel time between an origin zone and a destination zone by highway divided by the transit travel time).

Due to complexities for interpolating the per cent of total trips by transit from the surface, the staff then prepared, or wrote, a four-point linear interpolating program for computer use. In doing this, the staff had to determine the transit use values at several ranges of automobile availability and accessibility index in order to enter the interpolating equation.<sup>86</sup>

Trip-Interchange Modal Split Model. The surface developed by the Niagara Frontier Transportation Study differed from that developed in Southwest Wisconsin in that they divided their trips after trip distribution, recognized that a car used for a work trip will not likely be used for a shopping trip in a one-car family, and they used restructured modal split data from another study to both collaborate and extend their "response surfaces" or transit use estimating surfaces.<sup>87</sup>

In Buffalo, the decision was made that trip purpose, automobile availability, distance, and quality of service were the most important factors influencing transit use. The trip purposes selected were work and non-work because they considered that the work trip had "first call" on the travel alternatives available to a family; thus, having the greatest influence on the modal choice of all trips originating by that family. Automobile ownership was considered as an input into modal

split analysis as it gave an indirect measure of income; but it was replaced by automobile availability as this would account for the automobile rider work trips. The quality of service index used was a ratio of total automobile travel time (terminal time including walk times and parking maneuver times, accumulated link travel times, and a parking charge converted to time) divided by total transit travel time (terminal time including walk and wait times, accumulated link travel times, and transfer times, where applicable). However, the staff believed that a straight travel time ratio would mask large absolute travel time differences; therefore, they used the "airline distance," in miles, from origin to destination to offset this discrepancy. Since all mass transportation in the Buffalo area was by bus, the staff used Chicago transit use data, where rapid rail transit was available, to extend their "response surfaces" so that quality of service ratios of 1.0 or more, which indicates that a transit trip is equal to or faster than an automobile trip between the same two points, would be reflected in the "response surface."<sup>88</sup>

The per cent of transit use for either a work or non-work trip between any two zones was determined by adding the product of the transit use proportions at each zone, as determined from the "response surfaces"; an example of the use of this model is:

1. The origin zone is five miles from the destination zone and the travel time by transit is 30 minutes as opposed to 20 minutes by automobile, or the quality of service is 0.67.



2. Utilizing the "response surfaces" for both trip purposes and automobile availability for both the origin and destination zones; the following transit proportions were obtained:

a. Origin Zone

Trip Purpose/Auto Available	<u>Yes</u>	<u>No</u>
Work	0.90	0.10
Non-Work	0.70	0.30

b. Destination Zone

Trip Purpose/Auto Available	<u>Yes</u>	<u>No</u>
Work	0.12	0.45
Non-Work	0.04	0.16

3. The per cent of transit use by purpose is:

a. Work-- $(0.90)(0.12) + (0.10)(0.45) = 15.3\%$ , and

b. Non-Work-- $(0.70)(0.04) + (0.30)(0.16) = 7.6\%$ .<sup>89</sup>

### CHAPTER III

#### A BALANCED URBAN TRANSPORTATION SYSTEM

The goal of urban area transportation planning is the achievement of a balanced transportation system; such a system will insure the most efficient mix of mass transportation and highway facilities which support the desired level of future urban activity.<sup>89</sup> However, such a system generally will not be attained within the desired 20-year planning period<sup>90</sup> of the initially recommended transportation plan because of the auto-dominant structure of most American metropolitan areas. Therefore, the selection of a transit use estimating procedure which is "tailored" to the area is an important step in attaining the goal of a balanced transportation system.

The conclusions of this thesis indicate how many urban areas are trying to develop a balanced transportation system and how transportation planners evaluate transit use estimating procedures. The recommendations made are those that appear most desirable in attaining this goal through a cooperative, comprehensive, and continuing transportation planning study.

#### Conclusions

Although there are three procedures available for estimating transit use in urban areas, the two forms of modal split have been employed in most urban transportation planning studies. The reason for

this use is that only modal split directly relates transit and auto use, whereas direct generation gives the transportation planner an estimate of future transit use without relating transit use to auto use. And most metropolitan area transportation study staffs understand the need for a procedure to which "models," or simulates, all the urban area travel patterns because mass transit is part of most urban areas available transportation.<sup>91</sup>

Unless a policy decision was made at the outset of a study to not consider transit in urban areas having both modes of transportation, such as Detroit,<sup>92</sup> a form of modal split is preferred to direct generation. Assuming that no such policy decision is made, the transportation planner will test to develop either a trip-end or trip-interchange modal split procedure depending upon the type of procedure with which he is most familiar; however, he can use either type of modal split, if a policy decision dictates the use of a particular type of model.<sup>93</sup>

Each transit use estimating procedure offers some advantages, and some disadvantages, to the transportation planner because of the difference in the way they are developed during the analysis phase of a transportation planning process:

1. In the direct generation, the estimating procedure is developed using the land use and population characteristic output of the urban activity analysis.
2. In the trip-end modal split model, the estimating procedure is developed after the base-year trip-ends have been generated by trip generation.

3. In the trip-interchange modal split model, the estimating procedure is developed after the base-year production and attraction trip-ends have been linked using trip distribution.

The advantages of a direct generation procedure are:

1. It is the easiest to develop as it does not require any relationship between transit trips to automobile trips; thus results of the process are in terms of trips, not a percentage of total trips.

2. It appears to be the easiest way of introducing transit use into the forecasting process for an area which has no existing transit facility because it does not compete with automobiles for total trips.

However, its disadvantage is due to the fact that it does not relate transit trips to automobile trips, and a substantial over-estimation or under-estimation of future trips could result because of this lack of relationship; for example, when forecasted, the procedure might indicate an increase in transit use and the forecast of automobile trip might also indicate an increase of automobile use, but combined they would indicate total trips in excess of what would have been indicated had they been related.

Because modal split models have been used in transit use estimation more often than direct generation, transportation planners have pointed out the advantages and disadvantages of each modal type; for simplicity, the disadvantages of a modal will not be indicated, as it is generally considered an advantage of the other, except in the instance where amplification can be given, to allow the reader to determine which modal split models best meet his transit use estimating

needs. Regardless of the advantages or disadvantages indicated for either model type, there is little systematic knowledge available to determine that one is better than the other,<sup>94</sup> and in cases where one model has a distinct advantage over the other, research is being done by its advocates to overcome the objection.

The advantages of the trip-end model are:

1. Separate distributions of transit and automobile trips are made over their respective networks because of the variations in trip lengths.<sup>95</sup>
2. This model is simpler and more economic to develop as it requires less data for input.<sup>96</sup>

The advantages of the trip interchange model are:

1. Because the characteristics of both ends of a trip are considered, it does not "freeze" transit use, which should be a variable changing as the trip and characteristics change.<sup>97</sup>
2. It is more sensitive to the zone-system relationships which will change when a new transit facility is introduced.<sup>98</sup>

The disadvantage that each mode of transportation is not distributed over its own network has been overcome, to some extent, in that a modified network which indicates a transit facility which has a separate right-of-way and the highway facilities and computer program have been developed for transportation planning.<sup>99</sup>

### Recommendations

Far more important than the recommendation of a technical tool to use in transit use estimating is insuring that the urban transportation planning study is cooperative and comprehensive through the planning phase. It is apparent that several transit use estimations are developed for the justification of one facility over the other, whether it be mass transit or highway. One reason for this apparent bias is that in many urban areas a policy decision was made to justify a rail transit system or ignore the effect of transit. Another is a chasm that exists between the planner and engineer, generally resulting in a study control debate between a local or regional planning agency and a State highway department, in that planners failed to give the engineer specific enough information for their work and the engineers have failed to be specific enough in their requests for planning information.<sup>100</sup> Either of these reasons will result in the waste of public resources as any transportation plan produced under these influences will not be efficient and economical, utilizing the best of each mode of urban transportation. Therefore, it is imperative that all agencies interested in the development of an urban area fully cooperate in the development of the area's urban transportation plan; because failure to cooperate will result in a costly restudy process to insure that both modes of urban transportation are adequately considered which has occurred in some metropolitan areas.

Once the agencies cooperating in the transportation planning process have determined their major responsibilities, as to data or work

required as all participants should have the opportunity to review the work of others; the selection of the technical tools for transit use estimating and the other analysis and forecasting procedures is relatively easy following these guidelines:

1. All assumptions made should be documented.<sup>101</sup>
2. All variables used in the final procedures should be logical, stable, easily forecast, and easily maintained.<sup>102</sup>
3. The level of analysis used in developing each procedure must be equal. For example:
  - a. If a "peak-hour" model is to be used for transit use estimating, a "peak-hour" model should be used for all the other travel models.
  - b. If district-aggregates are used for transit use estimating rather than zonal-aggregates, the district-aggregates should be used in the development of the other travel models.
  - c. The same statistical measures should apply to the acceptance of any model; however, a model of lesser statistical validity may be accepted after it is firmly established that the model is the best that can be obtained.<sup>103</sup>

There appears to be a definite hierarchy of transit use estimating procedures from the direct generation of transit trips through the trip-end modal split to the trip-interchange modal split. Therefore, it is recommended that a trip-interchange modal split be used whenever possible and when this is not possible that the higher of the two remaining procedures be used as an interim procedure with the goal of ultimately

developing a trip-interchange procedure for the area. However, there should be lower limits as to the type of transit-use estimating procedure that should be accepted, the recommended lower limits are:

1. Direct generation should be permissible only in small (less than 250,000 population) metropolitan areas having a low rate of transit use (less than 5 per cent of total trips).

2. Trip-end modal split models should be least analytical form of transit estimation permitted in small metropolitan areas having a high rate of transit use (5 or more per cent of the total trips) or in medium (250,000 to 750,000 population) metropolitan areas with a low rate of transit use.

3. Trip-interchange modal split models should be the only transit-use estimating procedure permitted in large metropolitan areas (750,000 population and over) having a high rate of transit use.

4. All urban area transportation studies should contain a transit use estimating procedure.

Similar recommendations have been made by other transportation planners in the past;<sup>104</sup> but they have been reluctant to specify population levels or transit use rates because of the fear that if limits were set, they would become a reason why a less analytical model for transit use estimating was used by the transportation planning process.<sup>105</sup> However, each time transit use is re-estimated as the transportation plan is re-appraised;<sup>106</sup> the next higher form of transit use estimating procedure should be used in the new transit use estimation.



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